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Revision A

SPECIFICATION

FOR THE

MODERATE-RESOLUTION IMAGING SPECTRORADIOMETER

(MODIS)

EOS-AM PROJECT

MARCH 24, 1993

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

Specification for the
Moderate-Resolution Imaging Spectroradiometer (MODIS)

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ACRONYMS AND DEFINITIONS RELEVANT TO MODIS

b	- bit
B	- Byte (8 bits)
Band	- a wavelength interval in the radiated electromagnetic spectrum
bpi	- bits per inch
bps	- bits per second
CCB	- Configuration Control Board
CDR	- Critical Design Review
Channel	- a detector element and associated electronics in a spectral band
CR	- Change Request
Detector	- converts radiant energy to an electrical quantity; may consist of one or more elements in a common package
EOS	- Earth Observing System
EOSDIS	- Earth Observing System Data and Information System
FDDI	- Fiber Data Distribution Interface
FOV	- Field of View
FWHM	- Full Width at Half Maximum
GE	- General Electric, the spacecraft contractor
GIIS	- General Instrument Interface Specification (Payload to S/C)
GSD	- Ground Sample Distance
GSE	- Ground Support Equipment
GSFC	- Goddard Space Flight Center
IFOV	- Instantaneous Field of View
Lcloud	- Spectral Radiance from a 100% reflectance Lambertian scene
Lmax	- Maximum Spectral Radiance in a spectral band
Ltypical	- Typical Spectral Radiance in a spectral band
LWIR	- Long Wave Infrared, 6000 - 14400 nanometers
MTF	- Modulation Transfer Function
MWIR	- Medium Wave Infrared, 3000 - 6000 nanometers
NASA	- National Aeronautics and Space Administration
NEdL	- Noise Equivalent Differential Spectral Radiance; same as NESR
NEdT	- Noise Equivalent Differential Temperature
NESR	- Noise Equivalent Spectral Radiance; same as NEdL
NIR	- Near Infrared, 700 - 1060 nanometers
NIST	- National Institute of Standards and Technology
nm	- Nanometer (10^{-9} meter)
PAR	- EOS Performance Assurance Requirements Document
PDR	- Preliminary Design Review
Pixel	- The scan sample of the scene (object space sources) which for the MODIS Instrument is represented by one word of image data
PSR	- Preshipment Review
Rho	- Reflectance of a surface (of a scene)
S/C	- Spacecraft
SNR	- Signal-to-Noise Ratio

STE	- System Test Equipment
SWIR	- Short Wave Infrared, 1060 - 3000 nm
UIID	- Unique Instrument Interface Document (Instrument to S/C)
um	- Micrometer (10^{-6} meter)
VIS	- Visible Light, 400 - 700 nm
WBS	- Work Breakdown Structure
WSMC	- Western Space and Missile Center (EOS Launch Site)

1.0 SCOPE

This specification sets forth the performance, testing, calibration and assurance requirements of the Moderate-Resolution Imaging Spectroradiometer (MODIS) for the NASA EOS polar orbiting spacecraft.

The MODIS shall be a nadir viewing, cross-track observing continuously operating instrument designed to measure scene spectral radiance in thirty-six spectral bands in the visible (VIS), near infrared (NIR), short wave infrared (SWIR), medium wave infrared (MWIR), and long wave infrared (LWIR) spectral regions to permit various studies of the land, ocean and atmosphere. High radiometric accuracy and a five-year orbital operating life without servicing are required.

The MODIS shall have instantaneous fields of view (IFOVs) of 250, 500, and 1000 meters at nadir, from an altitude of 705km. In-flight calibrations using the sun, moon, and on-board sources are required.

2.0 APPLICABLE DOCUMENTS

The following documents shall apply to the design, fabrication, and verification effort conducted in accordance with this specification, and shall be considered part of this specification. The version of the documents attached to the contract shall apply. In the event of conflict between this specification and any referenced document, this specification shall govern. The Unique Instrument Interface Document (UIID) will be the second document in precedence. Any contradictions between this specification and the UIID shall be brought to the immediate attention of the Technical Officer.

2.1 GSFC AND GENERAL GOVERNMENT SPECIFICATIONS AND STANDARDS

(1) Federal Standard 209D: Clean Room and Work Station Requirements, Controlled Environment

(2) NHB 5610.1: Handbook for Preparation of Work Breakdown Structures

(3) GSFC S-250-P-1C: Contractor Prepared Monthly, Periodic, and Final Reports

(4) GHB 5112.1: Performance Measurement System (PMS) Handbook

(5) NASA Ref. Publication 1124: Outgassing Data for Selecting Spacecraft Materials

(6) 420-05-01: EOS Performance Assurance Requirements for General Instruments

(7) 420-03-01: EOS Project Calibration Management Plan

(8) 420-02-02: EOS Project Configuration Management Plan

(9) 422-20-04: EOS MODIS-N Software Management Requirements

(10) GEVS-SE: General Environmental Verification Specification for STS and ELV Payloads, Subsystems, and Components, NASA Goddard

(11) GHB 7120.1: Work Breakdown Structure

(12) NHB 6000.1C: Requirements for Packaging, Handling and Transportation

2.2 MILITARY SPECIFICATIONS AND STANDARDS

(1) MIL-STD-130G: Identification Marking for U.S. Government Property

(2) DOD-D-1000B: Military Specification Drawings, Engineering and Associated Lists, for Categories, A, B, C, D, G, H, Using Form 2 Drawings

2.3 EOS POLAR SPACECRAFT INSTRUMENT INTERFACE SPECIFICATIONS

(1) 420-03-02: EOS General Instrument Interface Specification

(2) 422-21-05: EOS Unique Instrument Interface Document for MODIS

2.4 EOS REFERENCE DOCUMENTS

(1) Reserved

3.0 TECHNICAL REQUIREMENTS

3.1 REQUIREMENTS OVERVIEW

3.1.1 General

The MODIS shall observe the Earth surface cross-track about nadir on a NASA polar orbiting spacecraft of the Earth Observing System. MODIS will be used for observation of land, ocean and atmospheric characteristics of the Earth in visible and infrared bands.

The MODIS shall consist of an optical system with a cross-track scan capability, that produces, at the equator, contiguous scans at nadir from an altitude of 705.3 km. The MODIS shall employ detectors, associated electronics, appropriate means to define thirty-six spectral bands, solar and lunar calibration capability, and on-board spectral, radiometric and electronic calibration systems.

3.1.2 Spacecraft Interfaces

Unique MODIS interface requirements, including maximum power, mass, and dimensions, are contained in this specification.

General specifications for the interfaces between instruments and the EOS spacecraft are contained in the General Instrument Interface Specification (GIIS). Additional details of MODIS unique interfaces with the spacecraft shall be documented later by the MODIS contractor in coordination and in accordance with the Stage Release interface requirements of the GIIS.

3.1.3 Maintainability and Servicing

MODIS shall be designed to facilitate repair on the ground.

Any servicing performed in orbit will be at the level of replacing the entire instrument; no component or module replacement in orbit is anticipated.

3.1.4 Definitions of Required Instrument Models

3.1.4.1 Radiometric Math Model

A Radiometric Math Model is an analytical model used to: evaluate the end-to-end radiometric performance of the MODIS instrument; conduct sensitivity analyses; determine absolute and relative calibration accuracies; determine polarization sensitivity; identify major error contributors which can be eliminated during the design phase; identify impact of error budget trades; assess instrument performance in terms of Signal-to-Noise Ratio (SNR), Noise

Equivalent Differential Temperature (NEdT), stability in orbit, etc.

The model shall be related to actual test and calibration data; the model shall be updated and refined during the course of the MODIS development program until it simulates instrument performance accurately.

Also to be included in the model are on-board and preflight ground laboratory calibration algorithms and a data book that contains all pertinent measured data required by the calibration algorithms. The on-board calibration algorithms are used along with ground calibration data to demonstrate that the absolute and relative radiometric accuracies are being met. The on-board calibration algorithms are deliverables, in a form suitable for incorporation into the Earth Observing System Data and Information System (EOSDIS), which convert from digital counts to calibrated spectral radiances based upon all on-board calibration devices. The calibration data shall also be provided in a mutually agreed upon computer-compatible form.

The radiometric math model may be a coherent compilation of multiple models or software packages. It shall be written in a common agreed-to language and transportable to a Goddard Space Flight Center (GSFC) for Government use.

3.1.4.2 Thermal Math Models

Thermal Math Models are analytical models used to evaluate the thermal performance of the instrument. The thermal design model shall be composed of at least 250 nodes; this model shall have sufficient detail of all subsystems and critical interfaces to predict accurately absolute (K) temperature, temperature gradients, and heat flow between nodes and interfaces. These models shall be verified and refined after comparison with thermal test data. In addition, a "Surface Model" and a "Thermal Model" shall be prepared for instrument/spacecraft interface definition. Thermal Math Models are further defined in the GIIS and SOW.

3.1.4.3 Structural Math Models

Structural Math Models are analytical models used to evaluate the structural performance and microphonic sensitivity of the instrument. Test-verified structural math models of the instrument of adequate fidelity shall be developed.

A detailed model or models shall be developed which are capable of providing accurate internal elements and member forces, stresses, and displacements. These models need not be NASTRAN and may contain as many degrees of freedom (DOF) as necessary for accurate member force calculation. These models shall be verified and refined after comparison with structural test results.

A reduced structural math model of the instrument shall be prepared. The model shall be prepared in MSC/NASTRAN format and contain no more than 500 dynamic DOF. The model shall meet the requirements specified in the Contract Document Requirements List (CDRL) and GIIS. The model will be utilized in various statics and dynamics analyses. The accuracy of the model shall be verified by dynamic test data. The model shall be updated to agree with the structural test results.

3.1.4.4 Structural Model

A Structural Model is structurally and mechanically equivalent to a Flight Unit, but need not be capable of the optical or electrical functions of a Flight Model. The structure shall be made of flight materials. This model shall have a mass and mass distribution (center of gravity, moments of inertia) like that of a Flight Model. This model shall be used by the contractor to verify physically the structural and mechanical design and to provide the mass distribution.

3.1.4.5 Engineering Model

The Engineering Model (EM) is used to evaluate design decisions and shall be similar to a Protoflight Model (PFM) in appearance, dimensions, function, performance, and interfaces. It need not be subjected to mechanical environmental tests. It shall incorporate parts and components of the same type called for in the PFM design, but they need not satisfy those specifications which assure a specified lifetime. The EM shall have the redundancy planned for the protoflight and flight units, except where justified otherwise by the contractor, and accepted by the Government. The EM shall be tested in air and thermal vacuum to verify performance and shall, as a goal, meet the performance requirements of this specification. The EM shall undergo a low-level modal survey to determine structural resonances.

3.1.4.6 Protoflight Model

The Protoflight Model is the first model which meets all contractual requirements for flight and undergoes the entire test and calibration program. It undergoes qualification test conditions and, after any necessary refurbishment, is planned for flight on the first EOS platform.

3.1.4.7 Flight Model

Flight Models are built and tested to satisfy all contractual requirements for flight. They undergo acceptance test conditions and are flown on an EOS platform.

3.2 OPERATIONAL REQUIREMENTS

3.2.1 Nominal Orbital Parameters

The MODIS will be flown in a 10:30 AM +/-15 minutes descending node, circular, sun-synchronous, near-polar orbit at an altitude of approximately 705km and in a 1:30 PM +/-15 minutes ascending node orbit with the same characteristics.

3.2.2 Operational Modes

The following are required operational modes for the MODIS: The MODIS contractor shall recommend the instrument configuration for these modes.

(1) Launch Phase and Orbital Acquisition Mode: To the extent possible, the platform will monitor the health and safety of the instrument during this time. The instrument will not be powered.

(2) Outgassing Mode: The instrument shall be non-operating or in partial operation during the early days of the mission, during which the optics, cooler, and other critical components shall be protected against contamination.

(3) Activation Mode: Initial turn-on and warm-up of the instrument.

(4) Mission Mode: Normal operation of the instrument, subdivided into day mode and night mode.

(5) Day Mode: Normal daytime full operating mode of the instrument.

(6) Night Mode: Normal nighttime reduced operating mode of the instrument, observing only in the thermal bands.

(7) Solar Calibration Mode: The instrument views a solar diffuser for a portion of each scan. This mode shall be available for a few minutes of each orbit, near the South Pole.

(8) Lunar Calibration Mode: The instrument views the moon for a portion of each scan while the spacecraft continues to face nadir.

(9) Spectral Calibration Mode: The on-board spectral calibrator is operating, while the instrument continues its mission mode.

(10) Survival Mode (Emergency Off Mode): This is for a spacecraft emergency; the intent is that all instruments will be reactivated incrementally upon spacecraft recovery. Initiation of this mode shall require a minimum of commands; ideally no instrument reconfiguration is necessary before operating power is cut off. If reconfiguration is required before powering off, MODIS shall hold the necessary provisions. Survival heaters connected to a separate spacecraft power bus shall be provided to protect the instrument in this mode.

3.2.3 Lifetime Requirements

The MODIS shall be designed to operate after delivery, within specification, without servicing, for six months prior to launch and five years in orbit, following a maximum period of eight years in storage plus two years of Integration and Test. The probability of meeting the five-year in-orbit lifetime requirement shall be at least 95% as determined by test experience plus analytical assessment. Redundancy may be incorporated to the extent necessary to achieve the required lifetime. If any ground-based servicing is anticipated because of the extended storage periods, this shall be identified in the Preliminary Design Review.

For purposes of lifetime evaluation, failure of the instrument is defined as loss of 25% or more of the bands or loss of more than 50% of the bands in one spectral region (i.e., VIS, NIR, SWIR, MWIR, or LWIR). A band shall be considered to have failed if the response in more than 25% of the detector elements within that band fall 50% below the response immediately before launch, or if the detector elements in the band cannot be calibrated to perform within specification.

Prior to integration on the spacecraft, the instrument shall be thoroughly tested and recalibrated if the storage period has exceeded one year. The PAR describes requirements regarding ageing and storage.

3.2.4 Natural Radiation Environment

The ionizing radiation environment of the EOS orbit is described in the GIIS document and in documents referenced therein. The MODIS will encounter a nominal background in its polar orbit and in addition traverse the South Atlantic Anomaly several orbits per day. The following paragraphs provide the requirements for the MODIS in the natural radiation environment.

3.2.4.1 Total Dose Performance

Early in the hardware design phase of the program, the contractor shall examine the orbital radiation environment in order to determine design requirements which will permit the instrument to continue to operate within specification at the end of five years in this orbital environment.

3.2.4.2 Transient Event Recovery

The South Atlantic Anomaly is characterized by an increasing density of energetic protons covering a spectrum of energies in the 1 MeV to 100 MeV regime. It may be unreasonable to attempt to shield sensitive electronic parts from all events caused by these particles. The contractor shall use circuits, parts, components, and appropriate shielding for the signal processing chain (detectors through buffer memory) which limit the impact in terms of the number of saturated detector sites at the focal plane and the number of degraded data words leaving the buffer memory. With regard to the focal planes, a single event shall affect no more than 3 contiguous spectral bands. Within any spectral band, no more than 5 contiguous pixels shall be affected for a period of time not to exceed 5 contiguous 1000m pixel readout times from the inception of the event. An event in the electronics following the focal planes shall degrade no more than 5 data words leaving the buffer memory. These requirements apply to events caused by particles having energy less than 20 MeV.

In the electronics which are not part of the signal processing chain, the instrument shall continue to operate nominally while traversing the South Atlantic Anomaly.

3.2.4.3 Verification of Performance Effects Caused by Radiation

Verification of these requirements shall be by analysis, radiation testing for total dose of custom electronics, and by on-orbit performance. Custom parts manufactured by a process certified to be tolerant to the EOS level of exposure over the five-year life do not require life testing.

3.3 OPTICAL REQUIREMENTS

3.3.1 Instantaneous Field of View (IFOV)

The IFOV is defined as that combination of focal length and detector size which results in a predetermined area on the Earth's surface being measured from the nominal 705 kilometer altitude where the area is measured at the 50% system response points and the signal is sufficient to meet the required SNR. The along-track IFOV at nadir shall be as given in Table 3.3.3. The Ground Sample Distance (GSD) is defined as the distance as measured on the ground between adjacent samples. The nadir GSD shall be equal to the value listed in Table 3.3.3. The tolerance on the IFOV is +0/-6% in the along-track direction. The cross-track IFOV need not be equal to the values listed in Table 3.3.3, if the distance traversed by the IFOV during sample integration equals the GSD. For all other sections of this specification, the cross-track IFOV shall be equivalent to the GSD.

Each detector within a band shall have an IFOV that does not differ from the mean by more than +/-5% in either dimension.

3.3.2 Field of View

The instrument shall scan the IFOV +/-55 degrees cross-track about nadir, using a method which does not introduce any image rotation.

3.3.3 Spectral Bands

MODIS shall operate in the VIS, NIR, SWIR, MWIR and LWIR regions, and shall provide spectral band measurements as listed in Table 3.3.3.

Table 3.3.3: Spectral Band Optical Characteristics

BAND	CENTER WL (nm)	WL TOLERANCE (+/-nm)	BW (nm)	BW TOLERANCE (+/-nm)	IFOV
1	645	4	50	4.0	250
2	858	2.2	35	4.3	250
3	469	4	20	2.8	500
4	555	4	20	3.3	500
5	1240	5	20	7.4	500
6	1640	7	24.6	9.8	500
7	2130	8	50	12.8	500
8	412	2	15	1.5	1000
9	443	1.1	10	1.6	1000
10	488	1.2	10	1.7	1000
11	531	2	10	1.9	1000
12	551	5	10	1.4	1000
13	667	+1,-2	10	1.7	1000
14	678	1	10	1.7	1000
15	748	2	10	1.9	1000
16	869	5	15	4.3	1000
17	905	2.3	30	5.4	1000
18	936	2.3	10	5.6	1000
19	940	2.4	50	5.6	1000
20	3750	19	180	22.5	1000
21	3959	20	59.4	23.8	1000
22	3959	20	59.4	23.8	1000
23	4050	20	60.8	24.3	1000
24	4465	22	65	26.8	1000
25	4515	22	67	27.1	1000
26	1375	6	30	8.0	1000
27	6715	34	360	40.3	1000
28	7325	37	300	44.0	1000
29	8550	43	300	51.3	1000
30	9730	49	300	58.4	1000
31	11030	55	500	66.2	1000
32	12020	60	500	72.1	1000
33	13335	67	300	80.0	1000
34	13635	68	300	81.8	1000
35	13935	70	300	83.6	1000
36	14235	71	300	85.4	1000

The high ranges of bands 29, 31, and 32 (defined in Table 3.3.4.2) have the same wavelength requirements as the normal ranges of these bands.

3.3.3.1 Definitions

These parameters relate to performance of the complete instrument system. See Figure 3.3.3.1.

a. Band Edge - The wavelength at which the response is half of the peak response; there is a lower and an upper band edge.

b. Center Wavelength - The wavelength midway between the band edges.

c. Bandpass (or bandwidth) - The wavelength interval between the lower and upper band edges. This is also referred to as the FWHM response.

d. One-percent Response Point - the wavelength, nearest to the center wavelength, at which the response is one-percent of the peak response; there is a lower and an upper one-percent response point.

e. Extended Bandpass - The wavelength interval between the lower and upper one-percent response points.

f. Out-of-Band Response Regions - The spectral regions beyond the extended bandpass.

g. Out-of-Band Response - The ratio of integrated out-of-band spectral response to integrated extended bandpass spectral response. This ratio includes both the upper and lower wings of the response.

h. Out-of-Band Blocking - The inverse of the ratio defined as the out-of-band response.

i. Edge Range - The wavelength interval, in nanometers, between 5% of peak response and 80% of peak response.

```
                100% --> --------
                           /       \
                          /         \
                         /           \
                        /             \
            50% --> +                 +
                        /|                 |\
                      /  |                 |  \
                 -       |                 |        -
___   - + <-- 1%         |                 |           -      + -   ___
-------+------------+-----------------+------------+-------
OUT OF |            |<-- BANDPASS -->|            | OUT OF
 BAND  |<-----------EXTENDED BANDPASS-------------| BAND
```

FIGURE 3.3.3.1

3.3.3.2 Edge Range

The edge range shall not exceed 50% of the bandwidth in any spectral band.

3.3.3.3 Out-of-Band Characteristics

The out-of-band response shall be less than 5%. Each one-percent response point shall be within 1.5 times the bandpass from the corresponding band edge. Compliance with this specification shall be determined for a source spectrum equivalent to the sum of Lcloud (the spectral radiance of a Lambertian surface of 100% reflectance, illuminated by the sun at a zenith angle of 22.5 degrees) plus an extended 300K blackbody. Lcloud is given in Table 3.3.4.1 for the VIS, NIR, and SWIR bands, and in Table 3.3.4.2 for the thermal bands.

3.3.3.4 Ripple

The response between the 80% of peak points of the bandpass shall always exceed 80% of the peak response.

3.3.4 Sensitivity Requirements

The sensitivity requirements for the MODIS spectral bands are given here. If the contractor determines that time delay and integration (TDI) is required for any band, this processing shall be done on board the instrument to minimize the data rate.

The instrument shall be capable of measuring spectral radiances from the Noise Equivalent Differential Spectral Radiance (NEdL) up to the Maximum Spectral Radiance at the entrance aperture of the instrument (Lmax). The instrument SNR shall be measured over this range of radiances.

As a consequence of increasing the IFOV areas 36% from Phase-B values, the sensitivity goal for each band shall surpass the requirements tabulated in Sections 3.3.4.1 and 3.3.4.2 by 36%.

3.3.4.1 Visible, Near IR and Short Wave IR Bands

Table 3.3.4.1 applies to the VIS, NIR and SWIR bands. It presents the requirements for NEdL and for SNR. It also presents Lmax, calculated for the expected maximum values of Earth surface reflectance plus atmospheric effects, for a solar zenith angle of 22.5 degrees. Additionally, the table contains the typical spectral radiance, Ltypical, at the instrument entrance aperture, for a solar zenith angle of 70 degrees. The required NEdL and SNR shall be achieved for Ltypical. The SNR is the ratio of Ltypical to the required NEdL. Lcloud is included in the table.

TABLE 3.3.4.1
MODIS VIS, NIR and SWIR Bands

BAND	CENTER WAVELENGTH (nm)	REQUIRED NEdL (*)	TYPICAL SPECTRAL RADIANCE (Ltypical) (*)	REQUIRED SNR	MAXIMUM SPECTRAL RADIANCE (Lmax) (*)	Lcloud (*)
1	645	0.169	21.8	128	685	457
2	858	0.123	24.7	201	285	293
3	469	0.145	35.3	243	593	570
4	555	0.127	29.0	228	518	559
5	1240	0.073	5.4	74	110	138
6	1640	0.027	7.3	275	70	68
7	2130	0.009	1.0	110	22	27
8	412	0.051	44.9	880	175	573
9	443	0.050	41.9	838	133	585
10	488	0.040	32.1	802	101	539
11	531	0.037	27.9	754	82	538
12	551	0.028	21.0	750	64	528
13	667	0.0104	9.5	910	32	471
14	678	0.008	8.7	1087	31	440
15	748	0.017	10.2	586	26	373
16	869	0.012	6.2	516	16	286
17	905	0.060	10.0	167	185	252
18	936	0.063	3.6	57	256	267
19	940	0.060	15.0	250	189	244
26	1375	0.04	6.0	150	89.9	113

* = Watts/m^2/um/sr

3.3.4.2 Thermal Emittance Bands

Table 3.3.4.2 presents requirements for the thermal emittance (MWIR and LWIR) bands. The table shows required NEdT and NEdL for typical scene temperatures and spectral radiances, Ltypical, of extended scenes. The table also gives the maximum scene temperatures, Tmax, and equivalent Lmax values which the instrument shall measure. The NEdT shall be met at the typical scene temperatures. Lcloud in included in the table.

3.3.5 Instrument Polarization Insensitivity

MODIS spectral bands 1 to 19 shall be insensitive to linear polarization as defined here. An analytical end-to-end polarization model shall be provided as part of the radiometric math model.

Table 3.3.4.2
MODIS Thermal Bands

BAND	CENTER WAVELNTH (nm)	TYPICAL SCENE TEMP Ttyp (K)	TYPICAL SPECTRAL RADIANCE Ltyp (*)	REQD NEdT (K)	NEdL (*)	MAX SCENE TEMP Tmax (K)	MAX SPECTRAL RADIANCE Lmax (*)	Lcloud
20	3750	300	0.45	0.05	0.000957	335	1.71	0.45
21	3959	335	2.38	2.00	0.015	500	86.00	0.67
22	3959	300	0.67	0.07	0.00190	328	1.89	0.67
23	4050	300	0.79	0.07	0.00217	328	2.16	0.79
24	4465	250	0.17	0.25	0.00218	264	0.34	1.44
25	4515	275	0.59	0.25	0.00620	285	0.88	1.53
26	(moved to Table 3.3.4.1)							
27	6715	240	1.16	0.25	0.0108	271	3.21	6.87
28	7325	250	2.18	0.25	0.0172	275	4.46	8.10
29	8550	300	9.58	0.05	0.00899	324	14.54	9.58
30	9730	250	3.69	0.25	0.0219	275	6.34	9.92
31	11030	300	9.55	0.05	0.00701	324	13.25	9.55
31hi	11030	400	29.1	1.00	0.247	400	29.08	9.55
32	12020	300	8.94	0.05	0.00606	324	12.10	8.94
32hi	12020	400	25.1	1.00	0.198	400	25.07	8.94
33	13335	260	4.52	0.25	0.0183	285	6.56	7.94
34	13635	250	3.76	0.25	0.0161	268	5.02	7.71
35	13935	240	3.11	0.25	0.0141	261	4.42	7.48
36	14235	220	2.08	0.35	0.0154	238	2.96	7.25

* = Watts/m^2/um/sr

Note: The high range of nonlinear bands 31 & 32 is 324K to 400K.

The polarization factor, as defined below, shall be no greater than 0.02 over scan angles of +/-45 degrees and wavelengths from 0.43 to 2.2um.

$$PF = (Imax - Imin)/(Imax + Imin) < 0.02$$

The contractor shall map the magnitude and direction of the polarization sensitivity of bands 1 to 19 over the full range of scan angles. This mapping may combine measurements for at least sixteen representative bands, including bands 9 through 17, with interpolation for the other bands.

The polarization model shall be adjusted to account for these data.

3.4 SYSTEM PERFORMANCE REQUIREMENTS

Performance and ground calibration data shall be analyzed and displayed in real time and in a quickly understandable form. This form shall generally be plots in engineering units.

3.4.1 Dynamic Range

MODIS shall be designed to operate over a dynamic range that extends from the noise floor (NEdL) in each spectral band to the maximum levels (Lmax) given in Tables 3.3.4.1 and 3.3.4.2. Instrument signal to noise ratio for radiances above Ltyp shall exceed the requirements at Ltyp.

3.4.2 Modulation Transfer Function

The MTF of the instrument system shall satisfy or exceed the values tabulated below. This MTF shall apply to both along-track and cross-track directions for a sine wave input. The Nyquist frequency has a spatial period equal to two IFOV's on the ground.

Frequency/Nyquist Frequency	MTF
0.00	1.0
0.25	0.9
0.50	0.7
0.75	0.5
1.00	0.3

The MTF requirements shall be satisfied for modulations of dark to Ltypical and for dark to Lmax, and shall be achieved for every channel of the different spectral bands in the instrument. The MTF's shall be measured at representative points of the VIS, NIR, SWIR, MWIR and LWIR regions.

3.4.3 Minimum Quantizing Resolution

A quantizer shall be included in the MODIS instrument to generate a digital data stream. The quantization steps shall be sized so that the signal-to-noise requirements for the typical spectral radiances and temperatures given in Tables 3.3.4.1 and 3.3.4.2 are met. Differential linearity of any signal quantizer shall be better than 0.5 of the least significant bit (LSB).

3.4.4 Transient Response (Bright Target Recovery)

The instrument shall be designed to minimize overshoot and ringing when the IFOV scans across a steep gradient in spectral radiance, from a maximum of Lcloud (Lmax for thermal bands) to a minimum of Ltypical. For this radiance step change the output signal shall have less than 1% overshoot and the output signal shall settle to within 0.5% of its final value within 2km.

3.4.5 Radiometric Performance

3.4.5.1 Radiometric Accuracy (Spectral and Amplitude)

The MODIS digitized and calibrated spectral radiances shall meet, in orbit, the accuracy requirements delineated below. More than one approach shall be used to verify the calibration accuracy and provide additional confidence in the measurements.

An end-to-end analysis of the total system shall be conducted to show that the system will meet the specified accuracy requirements over the full dynamic range.

The contractor shall consider internal heaters on key elements, or other instrument features which would aid in the post-launch verification of instrument calibration.

The frequency of calibration updates required in orbit for the instrument shall be recommended by the contractor. Operational procedures for routine, periodic calibration in orbit shall be developed.

3.4.5.2 Absolute Radiometric Accuracy

The MODIS absolute radiometric accuracy requirements are given in Table 3.4.5.2, and shall be established at the typical spectral radiance levels given in Tables 3.3.4.1 and 3.3.4.2. At any other radiance between 0.3Ltypical and 0.9Lmax the absolute accuracy of the radiance shall not exceed the values in Table 3.4.5.2 by more than 1%. These measurements shall be made at scan angles centered at 0, -45, and +45 degrees of the cross-track swath. Accuracies for the "hi" ranges (Table 3.3.4.2) of the nonlinear bands shall be 10%. All accuracies shall be established relative to National Institute of Standards and Technology (NIST) standards and standard procedures. These calibration accuracy requirements shall be satisfied for all cross-track angles.

Table 3.4.5.2
ABSOLUTE RADIOMETRIC ACCURACY REQUIREMENTS *

	REQT (ONE-SIGMA)
BELOW 3000 nm	5%
ABOVE 3000 nm	1% **
REFLECTANCE CALIBRATION	2%

* Based on use of multiple samples of a uniform, extended, non-polarized source. For bands below 3000nm, a tungsten lamp based source may be used for ground tests. For bands above 3000nm, the source shall have a black-body profile.

** Band 20 shall be 0.75% with a goal of 0.50%. Bands 31 and 32 shall be 0.50% with a goal of 0.25%.

3.4.5.3 Relative Radiometric Accuracy

3.4.5.3.1 Root Mean Square Deviation

The RMS deviation from the mean of the calibrated spectral radiance measurements within any spectral band when viewing a uniform calibration target shall be no greater than the NEdL values given in Table 3.3.4.1 and 3.3.4.2. This applies over the full range of spectral radiance levels.

3.4.5.3.2 Channel to Channel Uniformity

If multiple detector elements are used within a spectral band, then one dead element per band and no more than two dead elements per focal plane are acceptable. For all live channels, the calibrated mean output of each channel with respect to every other channel shall be matched to within the values of NEdL given in Table 3.3.4.1 for bands 1-19 and to within the values of NEdL given in Table 3.3.4.2 for bands 20-36. This matching condition shall be met when the instrument views a uniform constant spectral radiance field at levels of approximately 0.5Ltypical, Ltypical and 2Ltypical (or Lmax, if Lmax < 2Ltypical). This requirement does not apply in the high temperature ranges of the nonlinear (fire) bands.

3.4.5.3.3 System Electronic Crosstalk and Pattern Noise

The response of a detector element in a given spectral band (the sender) shall not cause an apparent change in either the response of another detector element in any band (the receiver) that is greater than one least significant bit (1-sigma) in response to a signal placed on the sender that is equivalent to the Ltypical for the sender and the receiver with zero incident radiance. This shall be based upon 12 bits for bands 1 to 32 and 10 bits for bands 33 to 36. This effect excludes those crosstalk effects associated with photogenerated charge diffusing through the bulk of the detector material and is measured as an increase above the diffusion crosstalk. With respect to the sender/ receiver in the same spectral band, the effect may be detected as information is read off the focal plane as a memory effect residual from the sender into the receiver's expected zero signal level. This paragraph does not apply during transient radiation events.

There are other coherent noise mechanisms that lead to structured patterns in the output data (e.g., herringbone or diagonal bars). These extraneous noise sources shall be imperceptible in data taken at the Ltypical radiance levels for each spectral band. This shall be verified by two-dimensional pictorial display tests used on representative bands.

3.4.5.4 Uniformity of Response Across an IFOV

The system response across each IFOV of each channel, in the along-track direction, shall be measured to a resolution at least as fine as 10% of its width. Within the central 80% of the width of the IFOV this response shall not vary by more than +/-20% of the mean.

3.4.5.5 System Noise Measurements

The signal-to-noise ratio shall be determined for all bands at a minimum of three equally spaced spectral radiance levels between 0.3 Ltypical and 0.9 Lmax to characterize the signal dependence of the system noise.

3.4.6 Geometric Performance Requirements

An alignment reference cube shall be mounted on the MODIS instrument to allow transfer of alignment from the instrument to the spacecraft mounting structure or to another reference on the spacecraft. The contractor may also use this cube during performance testing.

3.4.6.1 Pointing Knowledge

The angular location of each IFOV with respect to the MODIS alignment reference cube shall be known to within 30 arc sec (each axis, 1-sigma) at all scan angles. The contractor shall develop an algorithm to relate this knowledge to a cube on the spacecraft mounting structure.

3.4.6.2 Alignment Changes

The alignment of the instrument optical axis with respect to the instrument references and to the instrument mounting surface shall not change by more than 60 arc seconds and the relative alignment of all spectral bands shall remain within specification following any qualification level testing, launch, and in-orbit operation.

3.4.6.3 Spectral Band Registration

Coregistration of any two corresponding detector elements from different spectral bands having the same IFOV shall be within +/-20% of an IFOV in the cross-track and along-track directions, with +/-10% of an IFOV as a goal.

For spectral bands having different IFOV's, four 500m pixels and sixteen 250m pixels shall overlay the corresponding 1000m pixel at nadir. The tolerance on this coregistration requirement is 200m (+/-20% of the 1000m pixel), both cross-track and along-track with 100m as a goal.

Commandable adjustment of the crosstrack registration between focal planes shall be available to facilitate ground based and in orbit registration corrections in the crosstrack direction. The resolution of this adjustment shall be better than 25 meters.

3.4.7 Radiometric Amplitude Stability and Repeatability

Bias errors will be removed from the data during ground processing in order to improve radiometric accuracy. To accomplish this the instrument shall be stable over temperature and time as defined below.

3.4.7.1 Short-Term Stability

Short-term stability as defined here applies to all time scales less than two weeks. The mean radiometric response of each spectral band, corrected on the ground using in-flight calibration data, shall not differ by more than +/-1% (goal +/-0.5%) in the reflectance bands, and +/-0.5% in the emittance bands, from another response measurement made while viewing the same source operating at equal intensity, but separated by any time up to two weeks, including the effects of perturbations at the orbital period. These stability requirements shall also be met for short-term temperature excursions that may be expected to occur in the MODIS instrument.

3.4.7.2 Long-Term Stability

Long-term stability as defined here applies to all time scales between two weeks and five years. The mean calibrated radiometric response, as defined in the previous paragraph, of each band shall not change by more than +/-2% (+/-1% longer than 3000nm). Because of the impracticability of demonstrating compliance by actual measurement before instrument delivery, compliance can be demonstrated by an estimate of long-term stability based upon short-term tests plus analysis. This analysis shall use measured instrument rates of change as well as vendor supplied component/subsystem test data.

3.4.7.3 Spectral Band to Band Stability

The relative amplitude stability between all pairs of spectral bands shall be better than +/-0.5% measured at full-scale and +/-1% at half-scale. Each band shall be exposed to a source and the mean responses determined. To compare outputs between bands, the ratio of the means shall be calculated for each band with respect to a common band. In addition, ratios shall be calculated for selected (approximately ten) pairs of bands which will be used in common retrieval algorithms, e.g., ocean science pairs and land science pairs. These ratios shall remain constant within +/-0.5% at full-scale and +/-1% at half-scale over times separated by any interval up to two weeks, including orbital variations.

3.4.7.4 Wavelength Stability

The stability of both the center wavelength and the bandwidth shall be better than 2nm for the VIS bands, and better than 1% of the center wavelength for the other MODIS spectral bands. This includes shifts caused by changes of humidity, temperature, pressure, vibrations, or time.

3.4.7.5 Wavelength Accuracy and Precision

Wavelength measurements of the entire system shall be made on the ground, with an absolute accuracy of 0.5nm and a precision of 0.25nm, for wavelengths up to 1 um. The measurement accuracy and precision for all other spectral bands shall scale linearly with wavelength from 1um.

3.4.8 Stray Light Requirements

3.4.8.1 Stray Light Rejection

The MODIS shall reject unwanted scattered and diffracted radiation which affects the radiometric accuracy of the instrument. The instrument shall be designed to restrict stray light from any portion of the spacecraft or other spacecraft subsystem from entering the entrance aperture, solar calibration port, or space view port. In addition, stray light shall not cause any degradation to performance of a radiative cooler, if used.

For the spacecraft in an operational, nadir-facing attitude, the instrument response to any stray light striking the instrument on any surface (except the entrance aperture and within the instrument FOV) from any angle shall be less than one percent of the illuminating radiance, tested at the typical spectral radiances given in Table 3.3.4.1 and Table 3.3.4.2.

The source or sources used to irradiate the instrument for compliance testing shall have an intensity and view-factor of sufficient size to yield irradiance levels at any surface equal to maximum solar irradiance for any spectral interval within the entire MODIS spectral range.

3.4.8.2 Bright Target Within-Field Stray Light

For the VIS and NIR bands, when the MODIS views a 21 x 21 IFOV bright target of spectral radiance Lmax, which is surrounded by a region of spectral radiance Ltypical, the instrument response in the center of the bright target shall increase by no more than 0.004Lcloud when the brightness of the surround is increased to Lcloud.

3.4.8.3 Dark Target Within-Field Stray Light

For the VIS and NIR bands, when the MODIS views a 21 x 21 IFOV dark target of spectral radiance Ltypical, which is surrounded by a bright region of spectral radiance Lcloud, the instrument response in the center of the dark target shall decrease by no more than 0.004Lcloud when the brightness of the surround is decreased to 0.02Lmax.

3.4.8.4 Warm Target Within Field Diffracted Light

For the thermal bands, when the MODIS views a target of 5 x 5 IFOV at Ltypical which is surrounded by a region of cold radiance at 0.1Ltypical, the instrument response in the center pixel of the target shall increase by no more than 1% when the radiance of the surrounding region is increased to Ltypical.

3.4.9 In-Flight Calibration Requirements

An in-flight calibration system, including necessary algorithms, is required. This system shall be capable of calibrating the entire instrument from radiometric input to digital data stream output. Sources for amplitude calibration include the sun, the moon, and on-board visible and thermal sources. An in-flight solar calibration for the VIS and NIR bands is required; spectral calibration is also required for these bands. All absolute radiometric calibration sources shall fill the aperture.

3.4.9.1 In-Flight Radiometric Calibration

The MODIS shall provide for in-flight radiometric calibrations of all spectral bands, providing measurement of changes in gain of the optical, focal plane, and analog electronics subsystems. In-flight radiometric characterization, i.e., output digital value versus input spectral radiance, shall be made with sufficient accuracy to assure that the calibration requirements delineated in this specification are achieved over the dynamic range of 0.3Ltypical to 0.9Lmax.

3.4.9.2 In-Flight Wavelength Calibration

The MODIS shall provide for in-flight wavelength calibration of wavelengths up to 1um. The flight calibration shall be sensitive enough to detect a 1.0nm shift in the shortest wavelength band with a precision of 0.5nm. The detectable shifts and measurement precision for the other spectral bands below 1um shall scale with wavelength.

3.4.9.3 In-Flight Reflectance Calibration

The MODIS shall provide for in-flight reflectance calibration, using the sun to illuminate a solar diffuser surface which is viewed through the complete instrument optical system.

An on-board capability to monitor the solar diffuser characteristics shall be provided. Knowledge of the diffuser characteristics shall be adequate, when combined with other on-board calibrations, to maintain the calibration and stability requirements of this specification throughout the five year lifetime of the MODIS instrument.

The contractor shall demonstrate by test that the system provided to monitor the solar diffuser characteristics is sensitive enough and has the stability required to detect changes in the diffuser spectral reflectance in orbit, with a precision and accuracy sufficient to meet the calibration and stability requirements of this specification. This can be demonstrated on a test-to-test basis or by using averages of many tests sequences over periods of weeks to months.

3.4.9.4 In-Flight Lunar Calibration

Provision shall be made for using the moon occasionally as a calibration source. No spacecraft maneuvers shall be required to view the moon.

3.4.9.5 In-Flight Electronics Calibration

The MODIS shall consider provision of in-flight calibration of the entire analog and quantizing electronics by inserting an appropriate reference signal, such as a ramp or a stair-step and monitoring the electronic response at appropriate points. Failure in such circuitry shall not disable the signal carrying path.

3.4.10 Miscellaneous Instrument Requirements

3.4.10.1 Passive Radiant Cooler Decontamination and Margin

If a passive radiant cooler is used on MODIS, provision shall be made to decontaminate the cooler in the event that outgassing products or other contaminants condense on the cold surfaces. Any cooler doors used in this procedure shall be designed to be fail-safe. The cooler shall be designed with adequate margin for the five-year mission on EOS.

3.4.10.2 Ambient Conditions Operational Limitations

The contractor shall identify and document warnings regarding all sensitive parts, materials, and components and operational instrument limitations in appropriate required plans, procedures or lists.

3.4.10.3 Witness Mirrors

Witness mirrors, as required by the EOS GIIS to permit a check of contamination, shall be provided as part of the instrument.

3.4.10.4 Solar Flux into Optics or Radiators

Under certain unplanned spacecraft attitudes, the radiometer may scan through the sun on several successive scans. The radiometer shall be capable of scanning direct solar input in its 110-degree-wide FOV for a period of thirty seconds per event, and a total of five minutes in five years without detectable performance degradation or reduction in lifetime.

Likewise, any radiator shall be capable of withstanding unplanned direct solar input for a period of thirty seconds per event, and a total of five minutes in five years without detectable performance degradation or reduction in lifetime.

The radiometer shall return to its calibrated condition within ten orbits after any thirty second exposure to the sun.

Normal, expected solar inputs shall not degrade performance for any portion of the orbit.

3.5 COMMAND, CONTROL, COMMUNICATIONS AND TELEMETRY REQUIREMENTS

3.5.1 Command and Control Functions

The MODIS electronics system shall be configured to accept ground commands via the platform C&DH subsystem to perform all necessary instrument functions. A complete list of commands required to operate the instrument shall be developed. A definition of the function and necessity of each command shall be provided. No command or sequence of commands shall cause damage to the instrument.

3.5.2 Instrument Data Stream

The instrument data stream shall be sent to the platform C&DH subsystem. Selected housekeeping and ancillary data shall be included in the data stream.

3.5.2.1 Data Rates

The maximum instrument data rate, averaged over one minute, without data compression and before FDDI encoding, shall not exceed 11 Mbps, including packetizing overhead. The data shall be buffered to provide a steady data stream independent of scan timing. The night mode shall have a substantially lower data rate than the day mode; additional differing data rates for other modes may be proposed.

3.5.2.2 Data Packet Format

The MODIS data shall be packetized within the instrument. The format of the data packets transmitted to the EOS spacecraft is defined in the EOS General Instrument Interface Specification. All bands for a given pixel shall be in the same packet. The contractor shall propose method(s) for multiplexing the varying pixel sizes. Data shall be time tagged with real-time time code often enough to assure compliance with pointing and registration requirements.

3.5.3 Instrument Health and Status Monitoring

Telemetry data shall be provided to monitor the health and operating status of the instrument. These data shall be sufficient to permit pinpointing of failures within the instrument, and to permit accurate calibration of the instrument. Additional telemetry signals not included in the data stream may be available as appropriate on a test connector for use during ground testing; these shall be minimized.

3.5.3.1 Command Status

The complete command status shall be contained in the housekeeping telemetry and the instrument engineering telemetry to support health and status monitoring and calibration. Update rates shall be compatible with the frequency of commands which may be sent during testing or flight operation.

3.5.3.2 Housekeeping and Engineering Telemetry

Telemetry of instrument temperatures, voltages, currents, and other engineering parameters sufficient to evaluate the condition of the instrument, and to permit accurate calibration, shall be provided. Update rates shall be compatible with anticipated rates of changes of these parameters and shall also be sufficiently frequent to allow anomalous or transient behavior included in the packetized image data stream.

In addition to the housekeeping and instrument engineering data provided in the image data packet stream, selected health and status data needed for the operation of the instrument shall be provided through a separate housekeeping telemetry interface.

3.6 INTERFACE REQUIREMENTS

3.6.1 General

Interface requirements between the MODIS and EOS are given in the referenced documents, particularly the GIIS and the UIID. The GIIS contains interface specifications which apply to all instruments on the EOS spacecraft.

3.6.2 Unique

The MODIS UIID controls interface specifications which are unique to MODIS.

3.6.2.1 Power Consumption

The orbital average power consumption of MODIS shall not exceed 225 watts. The peak power consumption of MODIS shall not exceed 275 watts. Survival power shall not exceed 150 watts.

3.6.2.2 Mechanical Dimensions and Mass

The dimensions of MODIS shall not exceed:

Cross-track - 1.60 meters
Along-track - 1.00 meter
Height - 1.00 meter

The MODIS instrument shall be designed to mount crosswise on EOS. Appendages or structural elements (including coolers, doors, shields, diffusers, covers, structural mounts, etc.), which intrude into other volumes, extend past the edge of the spacecraft when deployed, or have limited areas greater than 1.00 meter high are subject to limitation and negotiation. Appendages shall not move through the field of view of a neighboring instrument.

The mass of MODIS shall not exceed 250kg.

3.6.2.3 DELETED

3.6.2.4 View Factors

The following fields of view have been factored into the EOS payload accommodations studies. Any views outside of these bounds are subject to negotiation.

3.6.2.4.1 Ground View

MODIS will have a clear ground view of five degrees wide along-track and 120 degrees cross-track, centered on nadir.

3.6.2.4.2 Sun View

MODIS will be located at the front (velocity) end of the EOS spacecraft. This will provide MODIS with the opportunity to view the sun when EOS is passing into the sunlight near the north pole of a descending morning orbit, or near the south pole of an ascending afternoon orbit. Obstructions in front of MODIS will be no lower than the zenith side of MODIS.

3.6.2.4.3 Space View for Passive Cooler and/or Radiometry

A space view is available along the long side of the EOS spacecraft for a cryogenic radiator. It may also be used for moon or cold sky calibrations.

4.0 SOFTWARE REQUIREMENTS

4.1 GENERAL

The contractor shall provide all software, both instrument-based and external, necessary to operate, test, calibrate, design, and analyze the instrument.

All software deliverable under this contract shall be consistent with the EOS MODIS-N Software Management Requirements, 422-20-04. All software shall be implemented in modular form with a descriptive functional title given to each module. All software modules shall be well commented. A comprehensive list of variables, parameters, constants, labels, and entry points with definitions shall be maintained for each module in a User's Guide. Flowcharts, labeling description, and their documentation shall be maintained for each module. Software assurance requirements shall be in accordance with the PAR. The instrument flight software interfaces with the S/C shall be designed to be compatible with the capabilities described in the documents contained in Section 2 of this document. All software which is required for operation and calibration through EOSDIS shall be compatible with that facility. The contractor shall participate in the review of EOSDIS instrument interface requirements.

4.1.1 Data Processing Software

The contractor shall provide all software necessary to analyze MODIS test data, for use at the contractor's facilities, at NASA facilities, at S/C contractor integration facilities, and for in-flight engineering analyses.

4.1.2 Instrument-Based Software/Firmware

The contractor shall design and provide in the instrument the capability to operate in the operational modes defined in Section 3.2.

4.1.3 Software for Operations Analysis

The contractor shall deliver with the STE software to accomplish the following on the STE; software for all items shall be in a high level language which is transferable with minimal effort to EOSDIS:

a. Instrument engineering and performance data analysis.

b. Quick-look engineering data analysis and display.

c. Produce video monitor and paper hardcopy images of the earth or of another scene.

d. Provide calibration algorithms and procedures including computation of calibration coefficients based on the on-board calibration sources as well as solar and lunar calibration sources.

e. Registration of spectral bands.

4.1.4 Command List and Description

The contractor shall provide a Command List and Description document containing descriptions and lists of all commands and command sequences necessary for operation of the instrument, to enable EOSDIS to generate and validate commands for in-flight or ground operation.

4.2 INSTRUMENT GROUND SOFTWARE

The contractor shall design and provide all ground support software necessary to operate, test and calibrate the instrument at the contractor's facilities, at NASA facilities using contractor-supplied GSE, at the spacecraft integration facilities using contractor-supplied GSE. This software shall support instrument verification, integration, monitoring of performance, ground operations, as well as supporting evaluation of data acquired during S/C integration and flight operations.

5.0 VERIFICATION AND CALIBRATION REQUIREMENTS

5.1 GENERAL

The MODIS contractor shall verify design, operation and performance to establish that the instrument meets the requirements of this specification, including the referenced documents. When tests or calibrations are conducted in differing ground environments, such as in gravity or air, justification shall be provided that the results are valid for orbital conditions. The verification program shall:

a. demonstrate design qualification;

b. allow flight acceptance test of the hardware and software, and demonstrate that the performance, operational, safety and interface requirements of this specification are met;

c. utilize calibration data and algorithms in the EOSDIS system and demonstrate full performance;

d. provide in-orbit evaluation to show that all verifiable performance requirements are met. Comparison shall be made to the ground test performance and any changes observed shall be analyzed and evaluated.

The contractor shall, as a minimum, perform all activities outlined below. The objective is to demonstrate through tests and analyses that all geometric, radiometric and calibration accuracy requirements are met. In those cases where testing is impractical, analytical techniques may be used. The system includes the instrument plus all associated test equipment and all calibration algorithms.

5.1.1 Verification Plan

The contractor shall prepare and maintain an overall MODIS Verification Plan as required by the PAR. This plan, together with the MODIS Calibration Management Plan, shall be sufficient to describe how all information needed for demonstrating specification compliance will be obtained, and to allow full interpretation of the orbital data to be obtained. In addition, this plan shall describe the use, interconnections, and function of all GSE equipment, including calibration sources and their use at the spacecraft contractor's facility.

5.1.2 Verification Specifications

The contractor shall prepare and maintain a MODIS Verification Specification as required by the PAR. This specification may be combined with the Verification Plan, but shall address more detail than the Plan. The specification shall define environmental parameters, and shall list the specific tests and parameter limits within this environmental envelope.

5.1.3 Verification Procedures

The contractor shall develop and maintain formal procedures for verification of the instrument or for subsystems which will be verified before incorporation into a larger assembly. The contractor shall include pass/fail criteria where applicable. All procedures and modifications shall be submitted to NASA for review and approval before use.

5.1.4 Calibration Management Plan

The contractor shall prepare and maintain an overall MODIS Calibration Management Plan. This plan shall define the calibration procedures and calibration sequences necessary for instrument characterization, and shall identify which level of assembly is to be calibrated in each case. This plan, together with the MODIS Verification Plan, shall be sufficient to obtain all information needed for demonstrating specification compliance and for full interpretation of the orbital data. Calibration accuracy analyses shall address both systematic and random errors. The contractor shall provide algorithms along with all necessary parameters to perform in-flight calibrations. This plan shall be submitted to NASA for review and approval.

5.1.5 Calibration Procedures

The contractor shall develop and maintain formal procedures for calibration of the instrument or for subsystems which will be calibrated before incorporation into a larger assembly. Final calibrations shall be performed on the entire instrument system, or on the largest practicable subsystem. The contractor shall include pass/fail criteria, where applicable. All procedures and modifications shall be submitted to NASA for review and approval before use.

5.1.6 Documentation of Test and Calibration Data

The contractor shall provide Specification Compliance and Calibration Data Books that present, as a minimum, the specification requirements, the IFOV plots, and the calibration results, such as bandwidth response curves overlaid one-to-the-other, and the required and measured signal-to-noise values. This shall be provided for all MODIS spectral bands. Calibration curves and algorithms shall also be provided.

5.1.7 Limits Program

The contractor shall provide and maintain software to monitor all command states, as well as selected voltages, currents, temperatures, and other parameters of the MODIS on a real-time basis. Certain functions which are determined to be critical shall be monitored and the software shall be designed to alarm if a critical fault occurs, and then automatically shut down the instrument if appropriate operator action is not taken. This software shall be designed to verify all operational modes of the MODIS and print out any out-of-tolerance items as they occur. This program shall be used any time the instrument is being operated from the System Test Equipment (STE).

All automatic sequences resident in the instrument or in any computer shall be capable of being bypassed by commands.

5.1.8 Controlled Documents

The MODIS Verification Plan, the MODIS Calibration Management Plan, and all individual test and calibration specifications and procedures shall be controlled documents. Each shall bear a cover sheet which will indicate all changes made after it has been approved and placed under configuration control. Each subsequent change, whether originated by GSFC or the contractor, shall be effected by Configuration Change Request procedures.

5.2 ENVIRONMENTAL TEST REQUIREMENTS

5.2.1 General

The MODIS protoflight and flight models shall be subjected to verification level and acceptance level environmental tests respectively. The units shall meet all specified performance criteria during these tests. The units are to be operated during these tests in a manner simulating actual operation during the various flight stages.

Any subsystem testing shall include the effect of the instrument itself, as determined by the contractor's analyses, on the environment for that subsystem.

The use of any environmental facility other than those at the contractor's own plant requires prior approval in writing from the Technical Officer.

Testing of all spectral bands shall be performed both in ambient (non-vacuum) and vacuum conditions.

Environmental test and analysis requirements and conditions for MODIS are contained in the PAR, GEVS, and the GIIS.

5.3 SYSTEM FUNCTIONAL AND PERFORMANCE TEST REQUIREMENTS

5.3.1 General

Tests shall be performed in accordance with the verification and calibration requirements of this specification and the PAR, to demonstrate that the instrument satisfies all functional and performance requirements of this specification.

5.4 SYSTEM CALIBRATION

5.4.1 Responsibility For Calibration

The calibration of the MODIS shall be the responsibility of the instrument contractor. Acceptance of the instrument is predicated upon its successful calibration. Since calibration is of highest priority, calibration shall be closely coordinated with the Technical Officer. Through the Technical Officer, representatives of the MODIS Facility Team whom he designates shall review the contractor's test procedures, shall be invited to witness the calibration process and shall be allowed to bring other calibration devices which may be of assistance during the calibration activity.

The calibration procedures shall produce the information needed for processing the data gathered in orbit. The calibration shall be conducted to 1) demonstrate system and subsystem performance, and 2) provide the data from which the instrument spectral radiance to digital output transfer function can be determined.

All tests which will be conducted to verify integration with the platform shall be conducted beforehand at the contractor's facility to establish an output data baseline.

5.4.2 Calibration of System Response

The contractor shall calibrate and test the instrument to determine its response to known stimuli and to determine all significant corrections to this response for the full expected range of instrument temperatures. The expected orbital thermal environment shall be simulated, using heaters or coolers as necessary, and the instrument shall be tested with its full complement of shields and thermal insulation. The definitive calibrations shall be carried out in thermal vacuum conditions.

5.4.2.1 Sources

For instrument radiometric calibration the contractor shall use sources of spectral radiance or irradiance traceable to NIST. The contractor shall provide a plan for maintaining the relationship between working sources and the NIST standards through the life of the contract.

5.4.2.2 Radiometric Calibration Temperature Plateaus

Radiometric response calibration measurements shall be made for at least three instrument temperature plateaus for the relevant modes of operation. The contractor shall determine the predicted peak-to-peak temperature excursion in orbit about the typical instrument temperature To. Calibration shall be performed at To, at the maximum and minimum predicted temperatures, and at any intermediate temperatures the contractor determines to be necessary in order to meet the instrument calibration accuracy requirements. The temperatures shall be well stabilized prior to conducting tests or measurements. Calibration data shall also be taken during the temperature transitions.

Additional analyses and dynamic temperature measurements shall be performed as necessary to permit the determination of radiances to the specified accuracies when instrument temperature is changing in orbit, e.g, when the instrument goes from night to day.

5.4.2.3 Linearity Calibration

Measurement of spectral radiance versus instrument output signal in all spectral bands shall be provided in sufficient detail to fully characterize instrument linearity.

5.4.2.4 Diffuser Calibration

The contractor shall provide a spectral calibration of the on-board diffuser deployed to its operating position. This calibration shall extend beyond the total angular range of the sun expected to be encountered in orbit. The contractor shall also measure the angles between the on-board diffuser normal and the instrument's X, Y, and Z axes to an accuracy of 0.1 degree.

5.4.2.5 Instrument Calibration Algorithms and Software

5.4.2.5.1 Radiometric

The contractor shall provide and maintain all real-time and off-line software necessary to generate a complete radiometric calibration of the instrument for the mission modes and calibration modes defined in this specification.

5.4.2.5.2 Spectral

The contractor shall provide and maintain all real-time and off-line software necessary to generate a complete wavelength calibration of the instrument in all spectral bands.

5.4.2.6 Formatted Real-time Data Dump

The contractor shall provide and maintain software to record and print a contiguous near real-time (generally a few minutes or less) decimal data dump which shall print out selected data just as it comes from the instrument for any mode of operation. This listing shall contain band and detector element identification for each radiometric data word.

5.4.3 Calibration Fixtures

The contractor shall provide and maintain test fixtures which shall be used for instrument test and calibration. The contractor shall provide a sufficient number of fixtures as required by the schedule. These fixtures shall be appropriate for both vacuum and ambient testing, as required. Fixtures for testing and calibration during spacecraft integration, using the contractor's stimuli, shall also be provided. The design shall minimize fixture dependent effects that may introduce errors during instrument test and calibration. Design of fixtures is subject to government review and approval.

5.4.4 Calibration of Temperature and Voltage Monitors

Temperature and voltage monitoring circuits shall be provided where appropriate and shall be sufficiently accurate to permit performance requirements to be achieved. Calibration curves in terms of counts versus volts or temperature shall be provided.

5.5 SPECIAL DATA REQUIREMENTS

5.5.1 History Storage Media

Whenever the instrument is operated from the System Test Equipment (STE), the contractor shall generate a digital history record which will be stored on some form of mutually agreed upon media and shall contain all MODIS output data plus all ancillary data necessary for the use of the instrument data. All media shall be provided by the contractor.

5.5.2 Special Data History

The contractor shall provide copies of selected portions of the recorded data as requested by the Technical Officer. This will include all or part of the calibration data plus other selected acceptance test data. These records shall be identified by date, test particulars and location on the storage media.

6.0 GROUND SUPPORT EQUIPMENT REQUIREMENTS

6.1 GENERAL

The contractor shall provide and maintain the MODIS Ground Support Equipment (GSE) throughout the duration of the contract. The GSE consists of the System Test Equipment including image processors and reproducers, the GSE software, calibration equipment, shipping containers, expendable materials and other necessary equipment and fixturing required to operate, test, calibrate, maintain the MODIS in a contamination-free environment and to support instrument-to-spacecraft integration and cross-calibration during spacecraft system level testing. The contractor shall perform tests necessary to demonstrate that all GSE is functioning properly and within specification. Some GSE will also be used by the contractor to support in-flight performance verification activities.

6.2 DELETED

6.3 SYSTEM TEST EQUIPMENT

6.3.1 General

The System Test Equipment (STE) shall be able to operate the MODIS during all testing at the instrument contractor's facility. The STE shall be capable of interfacing with the EOS platform GSE. The STE shall be capable of recording all instrument data received from the MODIS and of performing performance analyses of the data. It shall also perform off-line analyses of MODIS data contained on history "tapes".

There shall be two functionally identical copies of the STE. One copy, STE1, shall be delivered to the spacecraft contractor's facility at the time the first flight instrument is delivered. The STE1 will follow the spacecraft to the WSMC prior to launch, then be returned to the spacecraft contractor's facility for the next platform. STE1 will be used to perform functional and operational checks of a MODIS when it is either on the bench or on the spacecraft. It will also support instrument cross-calibration activities on the spacecraft. The other copy, STE2, shall remain at the contractor's facility throughout the program. Calibration sources shall also be delivered with STE1 for MODIS tests and calibrations at the spacecraft contractor's facility.

6.3.2 STE Requirements

(1) The STE shall be designed to duplicate as closely as possible all interfaces normally supplied by the

spacecraft. The contractor shall provide the spacecraft electrical interface hardware in accordance with design information provided by the spacecraft contractor. The contractor shall provide test points for monitoring all spacecraft related signals.

(2) The STE shall include automatic data processing equipment. The equipment shall, as a minimum, be capable of generating self test programs, execute command verification and sending programs, prevent instrument damage, monitor complete instrument command status, perform limit checks, record special data, and perform engineering analyses (e.g., band signal-to-noise analyses) of the MODIS radiometric data. Any recorded data shall be appropriately formatted and annotated so that it is readily accessible when needed either at the contractor's facility or elsewhere. The STE shall maintain a record of total running time on each instrument model in each mode of operation.

The recording media and format shall be mutually agreed upon by the contractor and the Technical Officer.

(3) STE operation shall be generally transparent to whether the instrument is alone or mounted on the spacecraft.

(4) The STE shall include all cabling necessary to carry out the required activities with MODIS. Breakout boxes shall be provided to check out each electrical interface.

(5) The STE shall have the capability of producing multispectral (false color) images on a monitor screen of any one, two, or three spectral bands, and of producing hard copy monochrome images of any one band.

(6) The STE shall have the capability of making a paper hard copy of instrument raw data, specially formatted instrument data and all other information which can be written on a storage medium.

(7) The STE shall provide a means of decommutating any word in the MODIS output data stream and displaying the total decimal count and its identification in arabic numerals as a continuous print. Status indicators and status bits shall be decommutated in real time and clearly displayed on the STE console.

(8) The STE shall interface with all ancillary test equipment including the standard radiance and irradiance sources. All essential data from this

external equipment shall be automatically integrated with the instrument data for correlation with instrument radiometric data.

(9) The STE shall provide test points for all significant MODIS and STE voltages and signals that are required to assess the operational health of each system.

(10) The STE shall include instrument data simulation for self-testing.

(11) The contractor shall maintain each STE, including the automatic data system and software, until the end of the contract, including any storage periods.

(12) Performance and ground calibration data shall be analyzed and displayed in near real time and in a quickly understandable form. This form shall generally be plots in engineering units.

6.3.3 Calibration Equipment and GSE Software

The calibration equipment and GSE software requirements are addressed elsewhere in this specification.

6.3.4 Shipping Container

The contractor shall provide environmentally controlled shipping containers and necessary ancillary equipment, in quantities to permit safe transport or storage of each instrument model.

Each shipping container shall be a suitable storage container and carrying case for each instrument. The container shall be capable of being pressurized with dry nitrogen and shall include shock protection, shock recorders, and temperature and humidity recorders. The container shall be designed to protect the instrument (a) in storage and (b) in transit via air freight and truck. The quantity of shipping containers required shall be determined by the contractor.

6.4 EQUIPMENT FOR AMBIENT OPERATION

Equipment as needed shall be provided to permit ambient (in-air) operation of the instrument with any cooled zones at their proper operating temperature. Provision shall be made to prevent water, ice or contamination from forming on the instrument during such tests.

6.5 ANCILLARY EQUIPMENT

6.5.1 Drill Templates

The contractor shall provide identical drill templates and use them for drilling the mounting holes in all physical models of MODIS. These templates will also be used for drilling the spacecraft mounting plate.

6.5.2 Handling and Lifting Fixtures

The contractor shall provide removable handling and lifting fixtures for the MODIS instruments, in accordance with NHB 6000.1C. These fixtures shall be designed to permit handling during assembly, test, shipment, and spacecraft integration operations. An appropriate set of these fixtures shall be shipped with the instrument as required for supporting tests and spacecraft integration at the spacecraft contractor's facility. The quantity of such fixtures shall be sufficient to permit necessary activities of all MODIS models to proceed without delay. The contractor shall provide additional handling equipment as necessary.

APPENDIX A

A.1 Measurements

A.1.1 Precision

In this specification the use of the term "measurement precision" is defined as the standard deviation of a statistically meaningful number of samples of that measurement.

A.1.2 Repeatability

In this specification the use of the term "repeatability" is defined as the allowable difference between successive measurements of the same parameter, or successive occurrence of the same event.

A.1.3 Accuracy

In this specification the use of the term "accuracy" or "measurement accuracy" is defined as the error (estimated uncertainty) in the measurement. This estimate shall include both systematic and random errors.

A.1.4 Tolerance

Tolerance is the allowable range for a specified parameter.

A.2 Tests

Verification by test consists of any or all of the following activities.

A.2.1 Functional Test

A functional test demonstrates an event or condition with a small discrete number of possible outcomes, e.g., a go/no-go or yes/no type event.

A.2.2 Performance Test

A performance test provides a measurement of an event or condition with a continuum of possible outcomes; this test measurement is then compared with the acceptable range of measurements for that parameter.

A.2.3 Design Qualification Environmental Tests

Design qualification environmental tests prove the flight-worthiness of the design and method of manufacture. Qualification is accomplished by imposing environmental levels more severe than those expected during ground, launch, and orbital operations. Environmental levels and durations imposed shall be in accordance with the GEVS document. Additional flight acceptance environmental tests are not required when design qualification environmental tests are performed on flight hardware.

A.2.4 Flight Acceptance Environmental Tests

Flight acceptance environmental tests are intended to demonstrate adequate workmanship and the absence of defects in flight hardware. This testing is accomplished by imposing environmental loads no more severe than the limit levels (i.e., those expected in actual use). Exposure times are not to exceed the durations defined for limit levels.

A.2.5 Analytical Model Validation Tests

Analytical model validation tests are tests intended to validate the mathematical models used in the analytical predictions. Applicable tests include, but are not limited to, modal surveys, static deflection, static load and thermal balance tests. The analytical model validation tests may be conducted on either engineering model hardware or flight hardware and not necessarily at the hardware level of assembly the model represents.

A.3 Analysis

Analysis is used in lieu of or in addition to testing to verify compliance with specification requirements. Where applicable, environmental levels used in analyses to qualify the design shall be determined by applying the design qualification factors of Section 3 of the PAR to the limit levels of the environment.

A.4 Assessments

Verification by assessment consists of any of the following activities.

A.4.1 Similarity Assessment

Similarity assessment is the process of assessing, by review of prior test data or hardware configuration and application, that the article under consideration is sufficiently similar or identical in design and manufacturing process to another article that has previously been qualified to equivalent or more stringent specifications.

A.4.2 Inspection Assessment

Inspection assessment is the process which may be used in lieu of, or in conjunction with, testing to verify design features (e.g., physical verification of compliance with drawings, wire coding, material compliance).

A.4.3 Demonstration Assessment

Demonstration assessment is the process by which demonstration techniques (e.g., service access, transportability, hardware interfaces, replacement provisions) are used in lieu of or in conjunction with test to verify compliance with the requirements.

A.4.4 Validation of Records Assessment

Validation of records assessment is the process by which manufacturing records are used to verify construction features and processes for flight hardware.

A.5 Environmental Limit Levels

Environmental limit levels are those which are expected in actual use in ground, launch, and orbital operations. Limit levels of environments for the Titan IV are specified in the documents referenced in the PAR. However, in determining appropriate structural load limit levels for MODIS and its elements, dynamic amplification by the EOS platform and within the MODIS instrument shall be considered. Thermal limit levels shall be determined, including the effects of the S/C.

A.6 Design Qualification Factors

Design qualification factors are used to modify the limit levels in order to accomplish the purpose of the verification activity or design qualification. These factors modify the limit level magnitudes but not the duration of exposure of the hardware to the environment.

A.7 Levels of Assembly for Verification

The hardware assembly levels used to identify discrete verification activities are defined as follows:

a. component - a functional subdivision of a subsystem, generally a self-contained combination of assemblies (a box) performing a function necessary for operation of a subsystem

b. subsystem - a grouping of one or more components, including interconnecting cables, which performs a particular operation

c. system - a grouping of subsystems

d. instrument - the entire (MODIS) flight assembly. A system often becomes a subsystem of a larger assembly.

A.8 Calibration

A procedure carried out to provide data which enable assembly outputs to be related to assembly inputs. The assembly may be the instrument or a subsystem of the instrument.